ANTENNA LABORATORY

Technical Report No. 39

LOG PERIODIC DIPOLE ARRAYS

by

Dwight E. Isbell

10 June 1959

Contract No. AF33(616)-6079
Project No. 9-(13-6278) Task 40572

Sponsored by:
WRIGHT AIR DEVELOPMENT CENTER

ELECTRICAL ENGINEERING RESEARCH LABORATORY
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

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ABSTRACT

A new class of coplanar dipole arrays is introduced. The antennas described provide unidirectional radiation patterns of constant beamwidth and nearly constant input impedances over any desired bandwidth. The broadband properties are achieved by making use of the principles of log periodic antenna design. One of the antennas discussed provides approximately 8 db of directive gain with an associated input standing wave ratio of 1.2:1 on a 75 ohm feeder, and this performance is independent of frequency. The free space properties of several of these arrays have been measured and the results are presented. The antenna configuration is simple, permitting practical methods of fabrication, and the design should prove useful in many applications. It makes possible, for example, the construction of "all wave" rotatable beams of very low cross section for use in the hf to uhf spectrum.

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Abstract

ILLUSTRATIONS

1. INTRODUCTION

Log periodic antenna design has been the subject of several papers over the past few years. The concept was first introduced in connection with a plane slot radiator having bidirectional, linearly polarized, radiation patterns of constant beamwidth and essentially constant input impedance over better than ten to one bandwidths[1]. Since that time many extensions of the original structure have been introduced providing a large choice of electrical characteristics all of which are virtually independent of frequency.[2,3] Log periodic antenna designs are available, for example, which provide omnidirectional, bidirectional, or unidirectional radiation patterns and either linear or circular polarization. The basic unidirectional elements all have moderate directive gains, and it has been shown that high gains are possible through application of array techniques[4] or by using the antennas as primary sources for large reflectors[5,6].

The antennas discussed in the following paragraphs provide electrical characteristics which are similiar to those of some of the antennas described in the above referenced papers, but they represent a departure in form. The log periodic designs which have been introduced to date have all been variations of a basic type involving combinations of a single composite element which is shaped to provide the log periodic characteristics. The antennas introduced here demonstrate that the log periodic principles can be applied to the design of arrays of conventional elements with frequency independent performance resulting. An important consequence of this as will be seen, is that these antennas permit at least a qualitative analysis of their operation in terms of familiar ideas, and they further tend to increase insight with respect to the operation of the original log periodic antennas.

2. SOME GENERAL CONSIDERATIONS

Although it has not, as yet, been possible to obtain precise physical understanding of the operation of the successful frequency independent antennas it is possible to put forth certain qualitative arguments in that direction. The following is an attempt to induce these arguments into the design of a wide band array using conventional elements.

If frequency independent performance is sought from a structure composed of resonant elements it is clear that the resonances must be staggered in order that as frequency is varied the function of the resonant element is transferred smoothly from one element to the next. In the case of an antenna array composed of similiar discrete elements this means that the physical dimensions of the elements must be scaled from one to the next in such a way that the desired frequency range is covered with elements of overlapping response characteristics. Since the characteristics of antenna elements are determined in part by their surroundings, it is necessary also to scale the environment.

Considering now a coplanar array of side by side dipoles in accordance with the above ideas, an arrangement of the type shown in Figure 1 is obtained. The lengths of the dipoles are related by a constant scale factor τ as defined in the figure. That is, given the length L of the element of order 0 in the array, the length of the elements of order n will be given by $\tau^n L$ where n takes on all integral values, positive or negative. Since it is also necessary to scale the environment, the spacings Δs between elements must be related in the same manner. If carried to the limit the array converges to the point 0 on the left as $n \rightarrow -\infty$ and becomes infinite in extent on the right as $n \rightarrow \infty$. If the elements of Figure 1 are fed in series by means of a common feeder from a generator located at point 0, the infinite structure will possess the property of logarithmic periodicity. That is, whatever the fields produced by an excitation frequency f they will be reporduced (apart from a change of scale) at all other frequencies given by $\tau^n f$. The variation in the fields between these frequencies will depend upon the degree of overlap in the individual element responses.

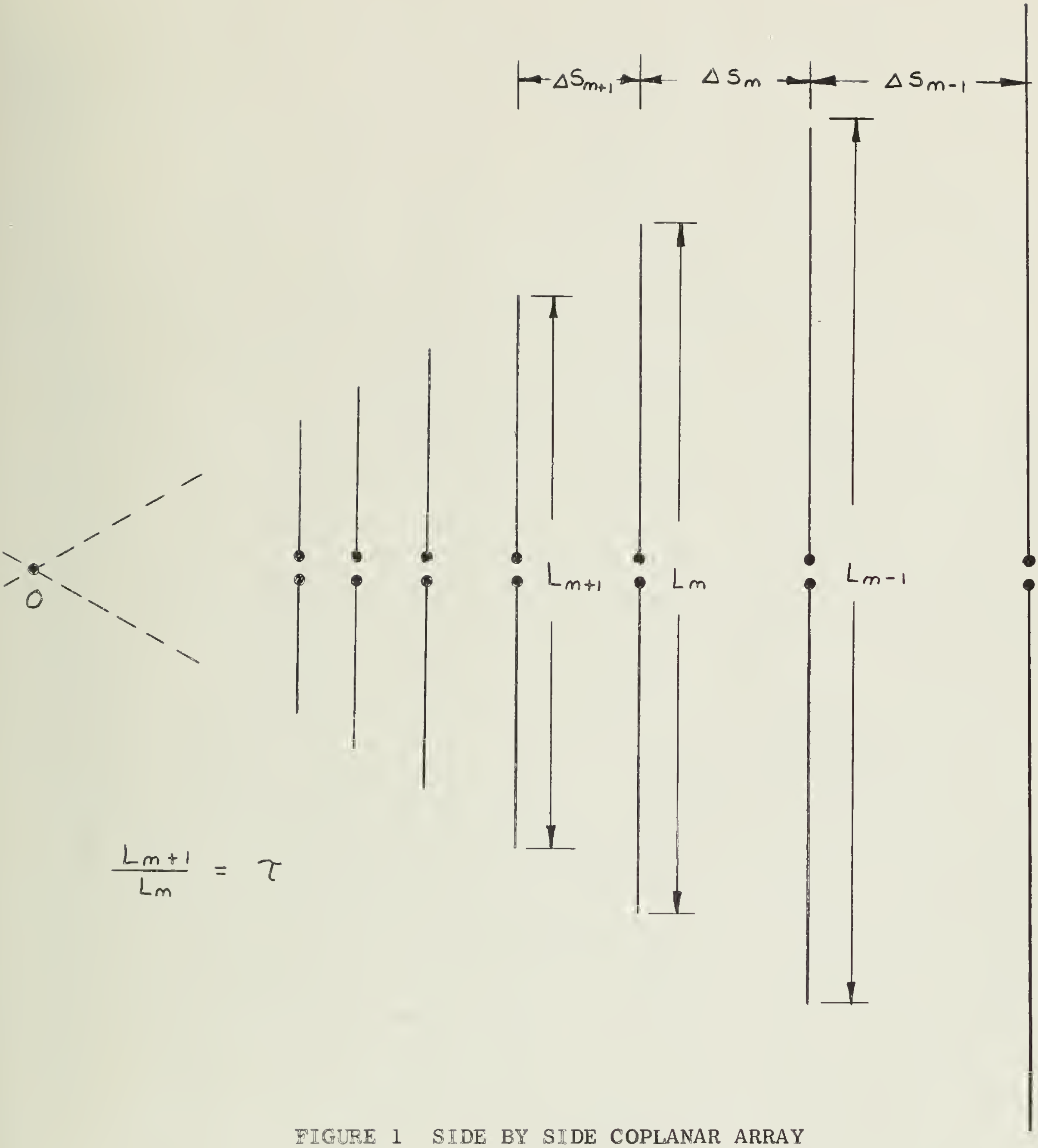


FIGURE 1 SIDE BY SIDE COPLANAR ARRAY

To be useful as a practical, broadband radiator it must be possible to truncate the array so that at all frequencies above some lower limit the truncated antenna performs like the infinite structure. This imposes a requirement for rapid attenuation of the incident wave along the feeder so that only negligible energy is reflected from the truncated end. If this situation occurs it follows that the array characteristic will be periodic in periods of bandwidth $1/\tau : 1$. If, furthermore, the variation in performance is negligible over a period then the antenna may be broadbanded to any desired degree by simply adding elements according to the general scheme.

Consideration must now be given to the method of feeding the array. Two methods of introducing the common feeder are shown in Figure 2. In both cases the dipole elements are attached to the feeder so that their respective terminal impedances appear in parallel across the line at the logarithmically varying intervals Δ s. In 2(a) the currents in the elements have the same relationship as the terminal phases so that considering the elements closely spaced, the phase progression of the currents in the array is to the right. In 2(b), however, the elements are connected so that a phase constant of π radians is added to the terminal phase of each element. This is accomplished mechanically by twisting the feeder 180° between each element.

A choice between these methods of feeding can be made on the basis of the following reasoning. If the array is to have the property of unlimited bandwidth with constant electrical characteristics, then it is clear that at any given frequency only a portion of the dipole elements can be excited. These elements must be such that the length of the excited portion of the array will be approximately constant in terms of the normalized distance x/λ measured from the array vertex. The elements which are not excited by the feeder should make no contribution to the performance so that coupling with the radiated field would be undesirable. It appears then that the radiation pattern of the array should have a null in the direction of the incident energy on the line. It has been pointed out that the array of Figure 2(a) is fed so that the element phase progresses to the right, and since this type of excitation is a condition for endfire in that direction this would seem to be an unsatisfactory method. Qualitative

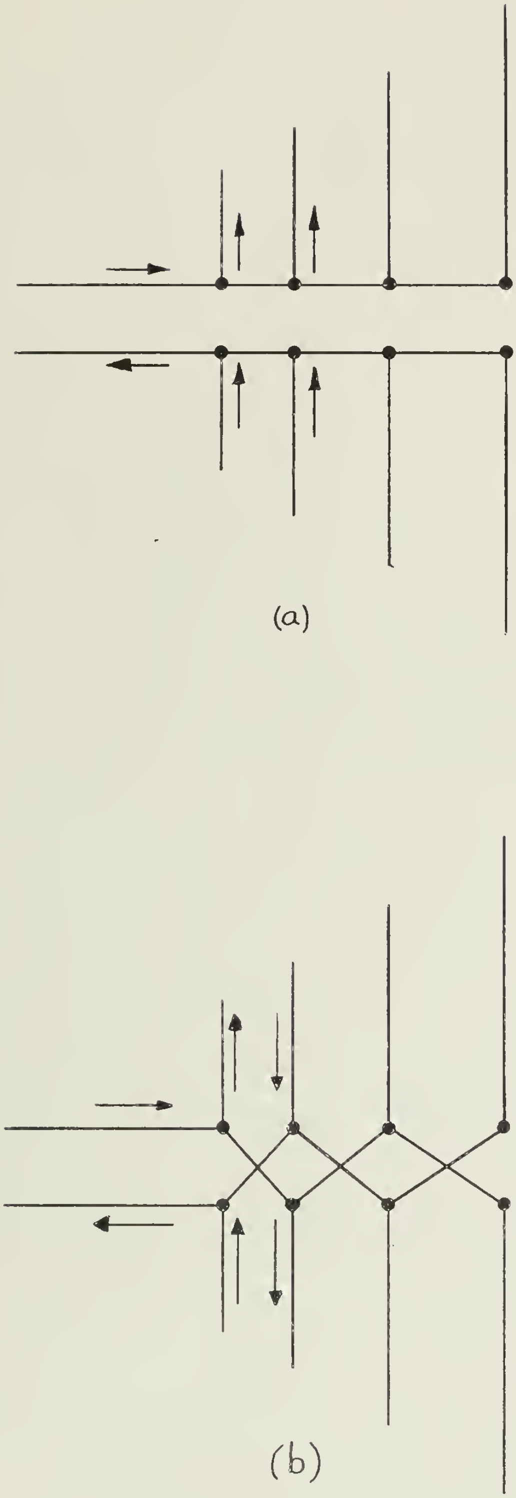


FIGURE 2 TWO METHODS OF EXCITATION

consideration of the array of Figure 2(b) however provides a more promising picture. In this case the short closely spaced elements are seen to be almost in phase opposition and hence radiate very little energy. Further out along the array where the spacing is larger and the elements are longer, the elements will radiate and the mechanical phase reversal effects a reversal in the direction of phase x progression so that the radiation pattern is endfire in the direction of the input terminals. With this method of feeding, the elements which radiate the most energy will be those near resonant lengths and their combined radiation pattern is toward the array apex as desired. As the frequency is increased the radiating elements appear closer to the apex of the array by an amount proportional to the change in wavelength so that the normalized array length remains approximately constant as the frequency is varied.

An experimental program was carried out to determine the electrical properties of arrays of the type shown in Figure 2(b), and it was found that this antenna, for certain parameter values, has essentially frequency independent performance over any desired bandwidth.

3. EXPERIMENTAL RESULTS

3.1 Model Description

The parameters describing the experimental arrays are shown in Figure 3. The structure is defined in terms of the geometric ratio τ, the angle α, and the characteristic impedance of the feeder. The feeder impedance has not been found to be critical, and for most of this investigation 105 ohm rigid open wire line was used. The method of obtaining the 180^o phase reversal between elements is shown in the sketch of Figure 4. The array is fed by means of a coaxial cable brought to the input terminals through one of the balanced line conductors. No balun is required for this method of feeding.

3.2 Effect of Truncation

One of the first things to be determined experimentally is the effect of truncation of the array. It is necessary that the electrical properties of the truncated structure converge to characteristic values as the frequency is increased as previously mentioned, it should be the case that above some low frequency limit, determined by the maximum physical dimension of the array, the properties are identical to those of the infinite structure.

If the antenna array is thought of as a linear passive, four terminal, network with input terminals at the apex and output terminals at the truncated end then it may be considered as shown in Figure 5. It is required that for the truncated antenna, the transmitted power P_t, through the network, be only a negligible part of the net power input, $P_i - P_r$. In other words, the transmission coefficient S_{12} of the network, must be small. It is essential that the antenna configuration convert, efficiently, the power incident on the feeder to radiated power P_R. The radiating efficiency is defined as

$$\eta_R = \frac{P_R}{P_i - P_r},$$

and in terms of the scattering coefficients this becomes

$$\eta_R = \frac{1 - |S_{11}|^2 - |S_{12}|^2}{1 - |S_{11}|^2}$$

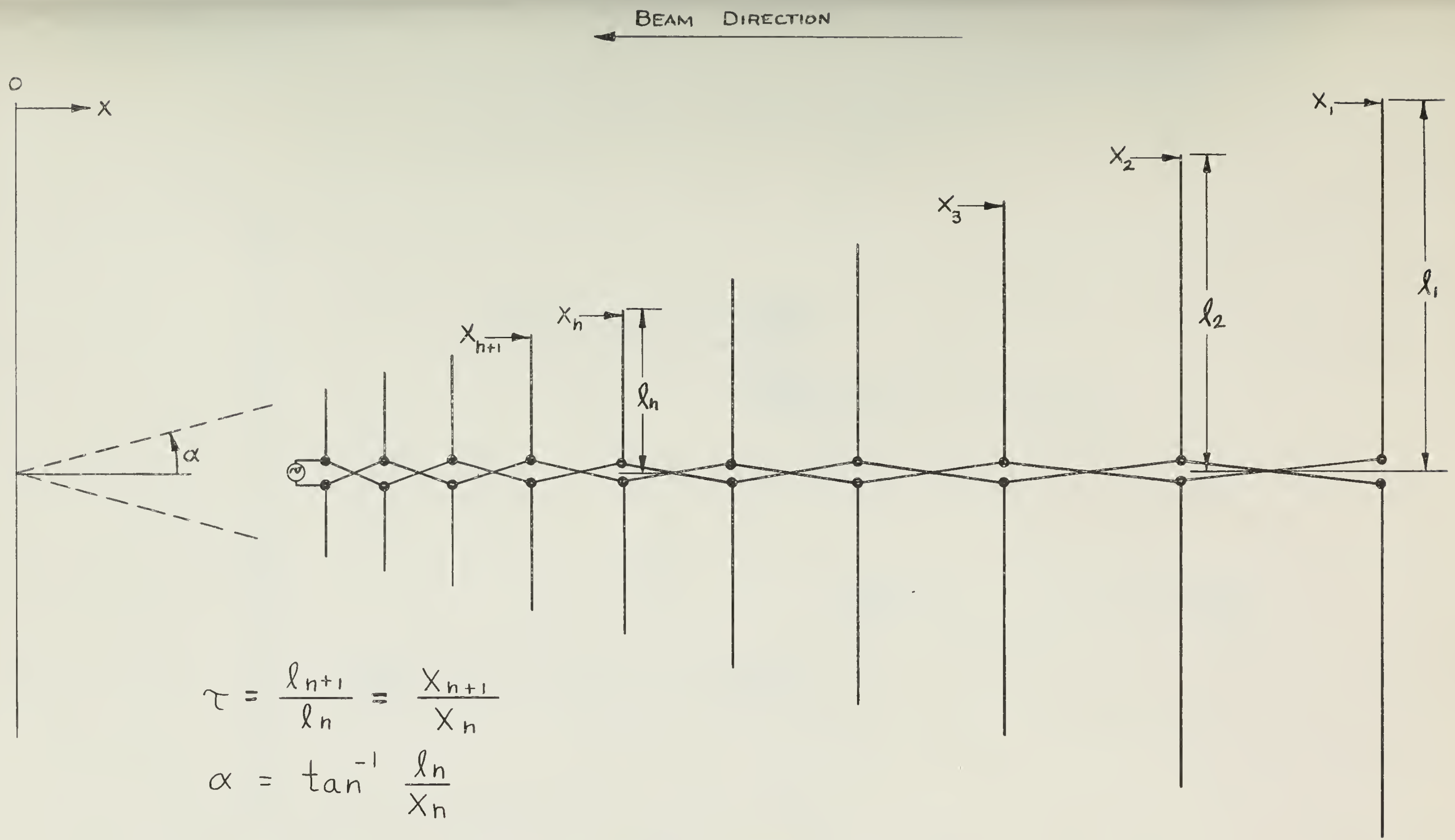


FIGURE 3 SCHEMATIC DIAGRAM OF THE ARRAY

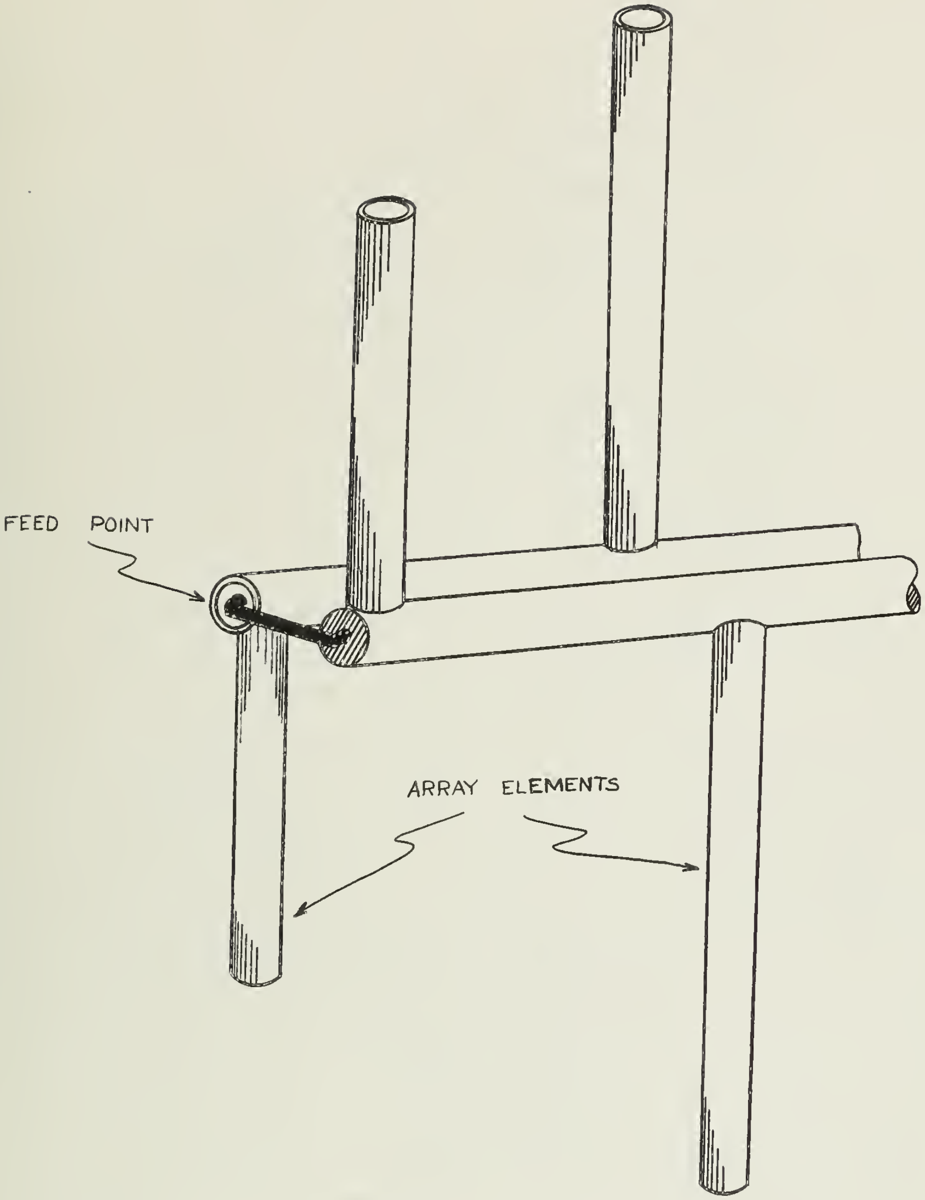
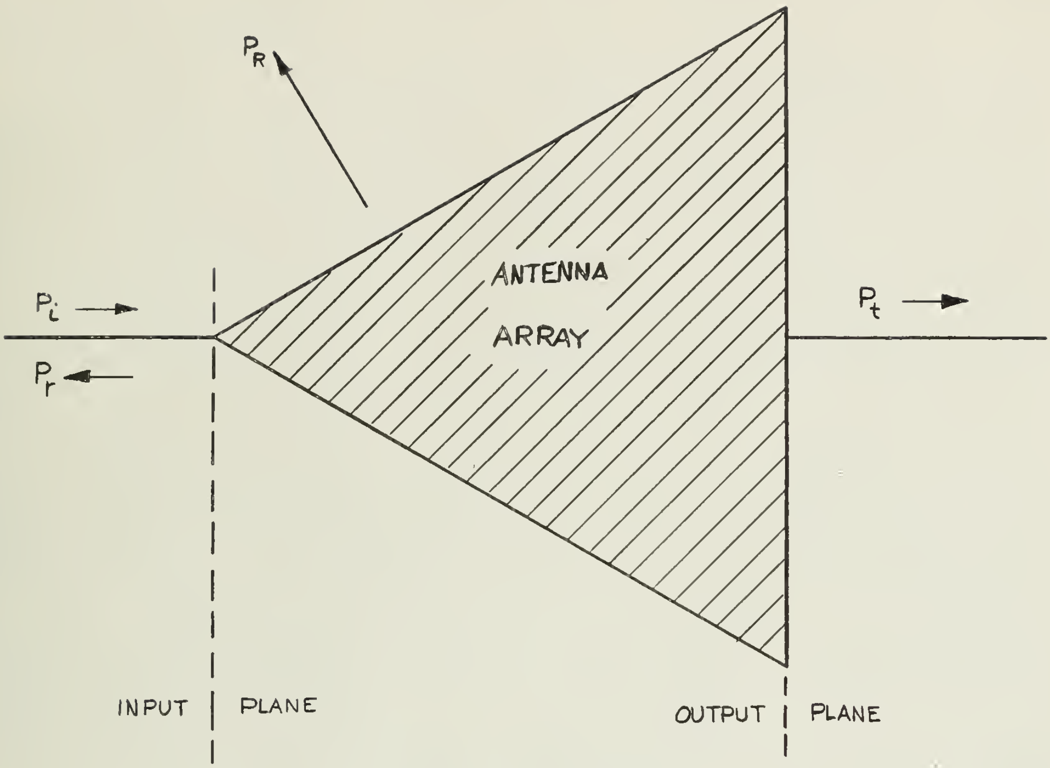


FIGURE 4 CONNECTION OF ELEMENTS TO BALANCED FEEDER



radiated power $P_R = P_i - P_r - P_t$

radiating efficiency $\eta_R = \dfrac{P_R}{P_i - P_r}$

in terms of the scattering coefficients

$$P_r = |S_{11}|^2 P_i$$

$$P_t = |S_{12}|^2 P_i$$

so that

$$\eta_R = \frac{1-|S_{11}|^2-|S_{12}|^2}{1-|S_{11}|^2}$$

FIGURE 5 THE ARRAY AS A TWO PORT NETWORK

Note that the efficiency so defined does not take into account the conductor losses in the elements.

A simple method of determining the scattering parameters of a two part network was introduced by Deschamps.[7] With this method the image of the unit circle in the output plane is determined experimentally and plotted in the input reflection coefficient plane. This is accomplished by a simple series of slotted line measurements of the input reflection coefficient as a function of pure reactive terminations at the output terminals. Determination of the unit image circle and its iconocenter is sufficient for determination of the scattering matrix elements.

The experimental apparatus for making this measurement is shown in Figure 6. The individual antenna elements were made from thin copper strips formed at one end so that they snap in place on the conductors of the open wire line. This procedure was found to be both simple and satisfactory although care was necessary in making the elements to ensure that they stood perpendicular to the feeder.

The radiating efficiency was measured for several of the arrays as a function of size. This was accomplished by starting with a few small elements near the apex in place and then measuring the scattering coefficients of the network as each additional element was snapped in place. A curve of radiation efficiency as a function of array size is shown in Figure 7 for one of the models tested. Notice that by the time an element of length $\lambda/2$ is added nearly 80% of the power is being radiated.

3.3 Input Impedance

The input impedances of the experimental models were measured using the same set up as shown in Figure 7. The array elements were arranged so that the terminals of the shortest dipole appeared at the junction between the coaxial cable and the balanced line. This procedure effectively truncates the array at both ends providing upper and lower frequency limits accordingly. Between these frequency limits the input impedance was found to behave in a manner characteristic of the design parameters τ and α, and several combinations were investigated.

The results of the impedance measurements are shown in Figures 8, 9, and 10. Each figure represents the variation of the input impedance as a

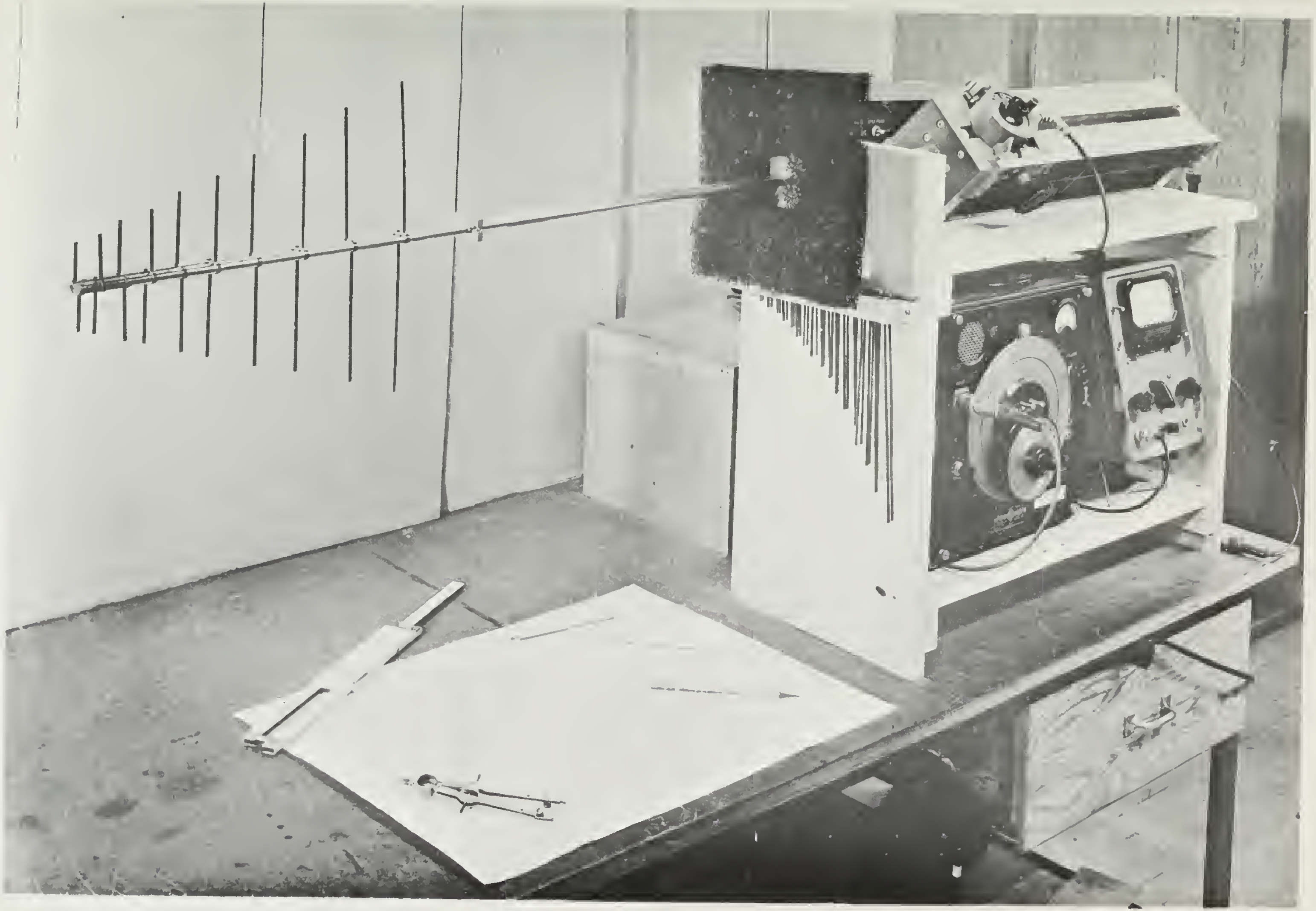


FIGURE 6 MEASUREMENT APPARATUS

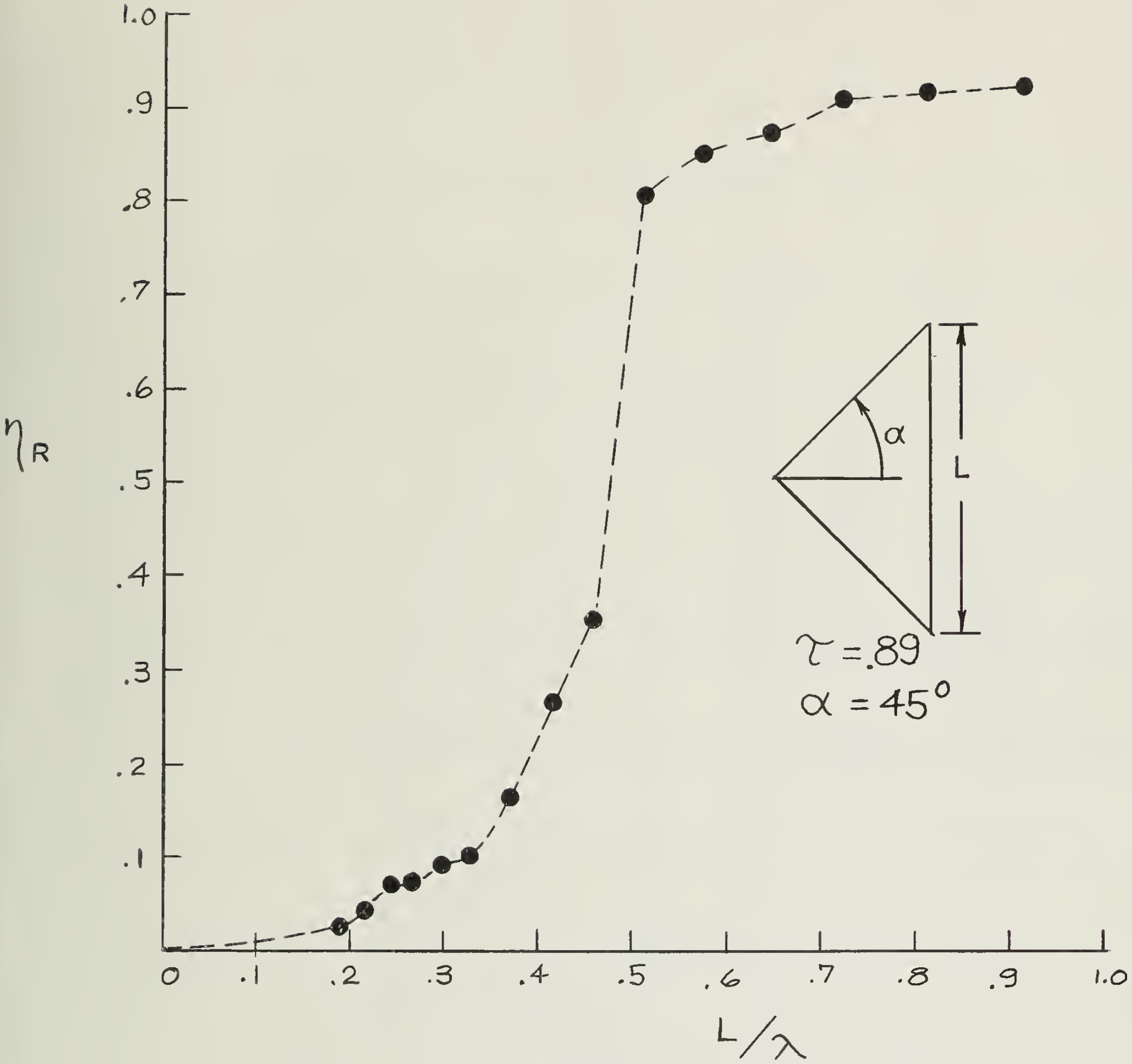


FIGURE 7 RADIATING EFFICIENCY VS. ANTENNA SIZE

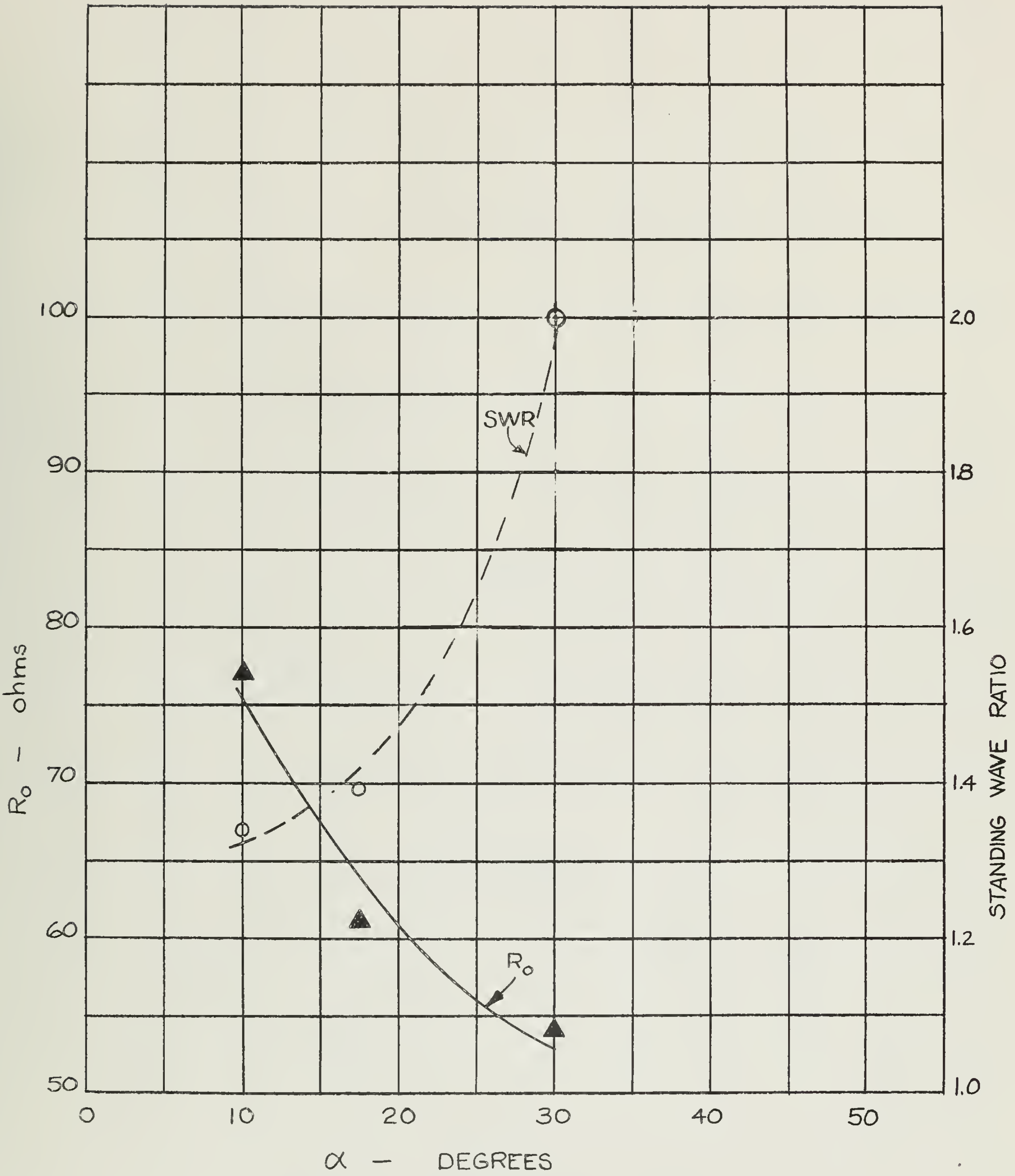


FIGURE 8 INPUT IMPEDANCE, τ = .95

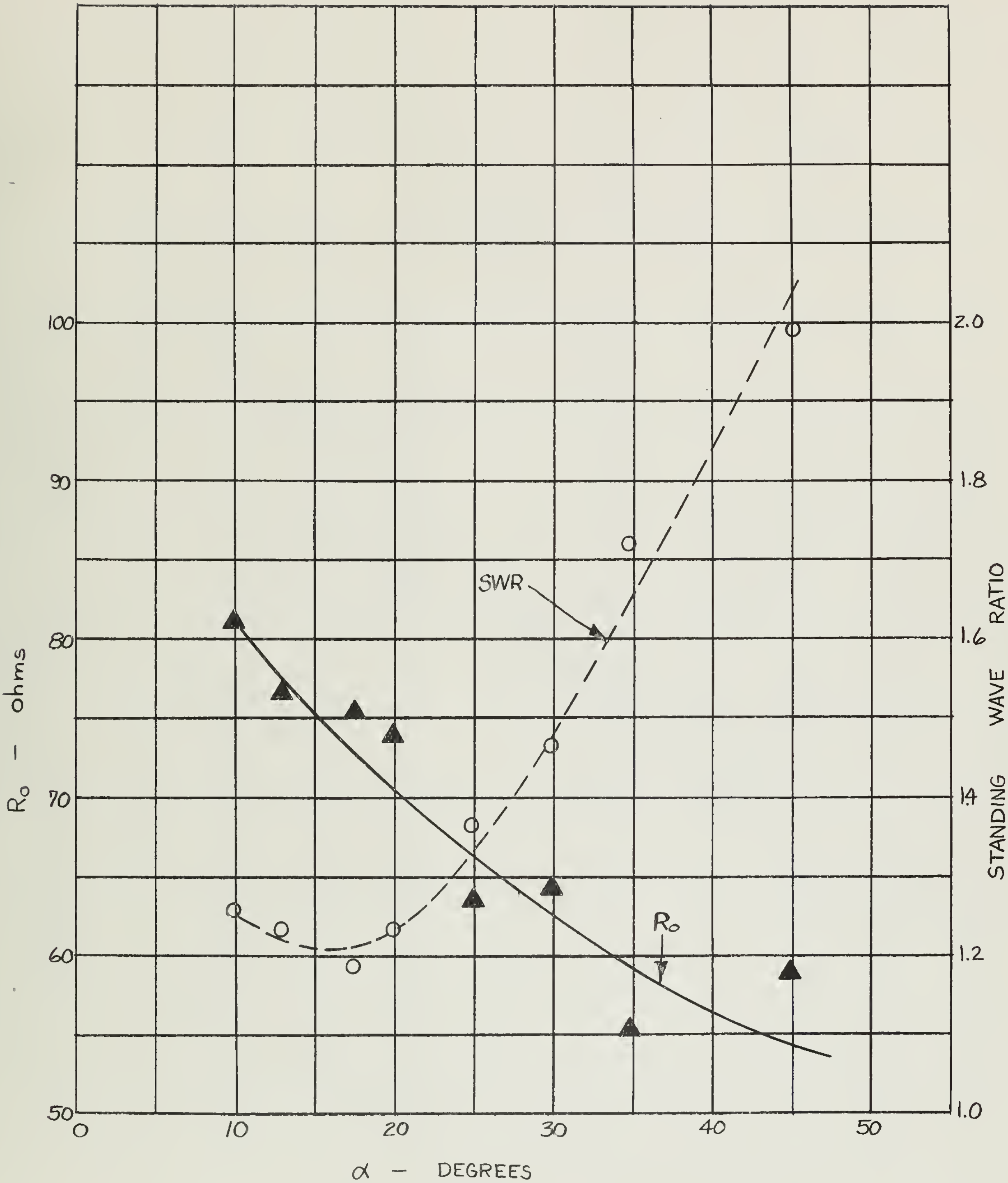


FIGURE 9 INPUT IMPEDANCE, τ = .89

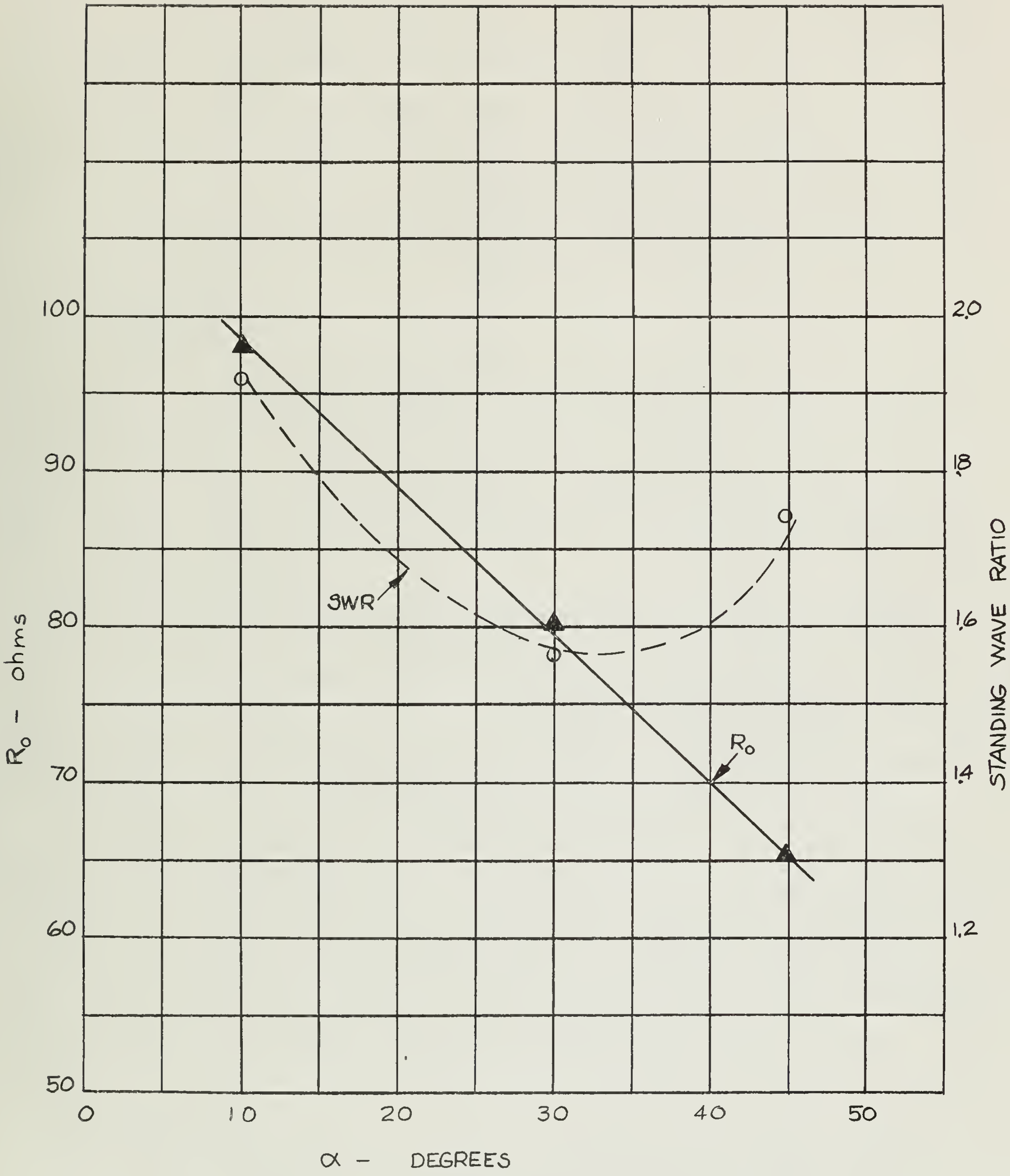


FIGURE 10 INPUT IMPEDANCE, τ = .81

function of α for a given value of τ. The solid curve represents the approximate mean resistance level R_o of the impedance locus and the dashed curve shows the corresponding voltage standing wave ratio with respect to R_o. If, for example, a 75 ohm coaxial cable is used to feed an array having $\tau = .89$ and α of approximately 17 degrees then the resulting standing wave ratio on the line will be about 1.2:1 over any desired range, depending on the locations of the two truncations. All impedances were measured with the balanced feeder terminated in a short circuit a distance $\ell_1/2$ beyond the largest element.

3.4 Radiation Patterns

The characteristic radiation pattern is an endfire beam in the negative x direction, as indicated in Figure 3. The beamwidths are nearly constant in both principal planes and the directivity is a function of both τ and α. It is not, therefore, possible to control the pattern independently of the input impedance, but it should be possible to make satisfactory compromises when selecting parameters.

Radiation patterns were measured for the same range of parameters as were the impedances. A few of the experimental models are shown in Figure 11. They were constructed of .125 inch diameter tubing for the balanced line and .050 inch diameter wire for the elements. The elements are attached to the feeder with soft solder, and the array is fed with miniature coaxial cable inserted through one of the balanced line conductors.

Figures 12, 13, and 14 show how the characteristic radiation patterns vary with α for three values of τ. The estimated directive gain as a function of α is shown in Figure 15. Cross polarization for these antennas is considerably better than 20 db below pattern maximum if care is taken with regard to mechanical symmetry. Pattern measurements, like the impedance measurements, were made with the balanced feeder terminated in a short circuit a distance $\ell_1/2$ beyond the terminals of element ℓ_1.

3.5 Bandwidth Control

Since the log-periodic dipole array may be truncated at both ends and still provide nearly frequency independent performance over some range of frequencies, it is clear that, in the interest of saving size and weight, a particular antenna should be designed to meet the minimum required band-

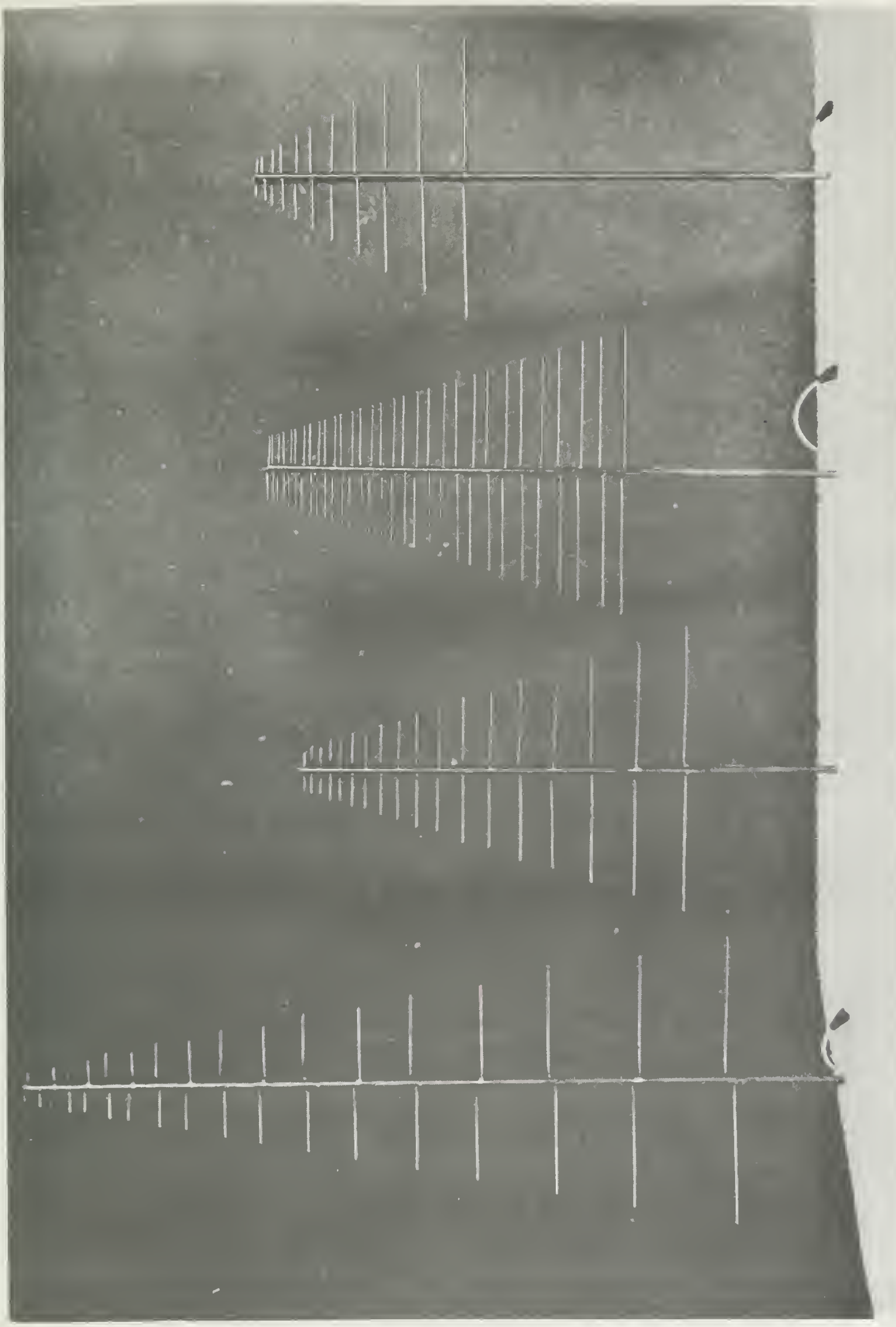


FIGURE 11 RADIATION PATTERN MODELS

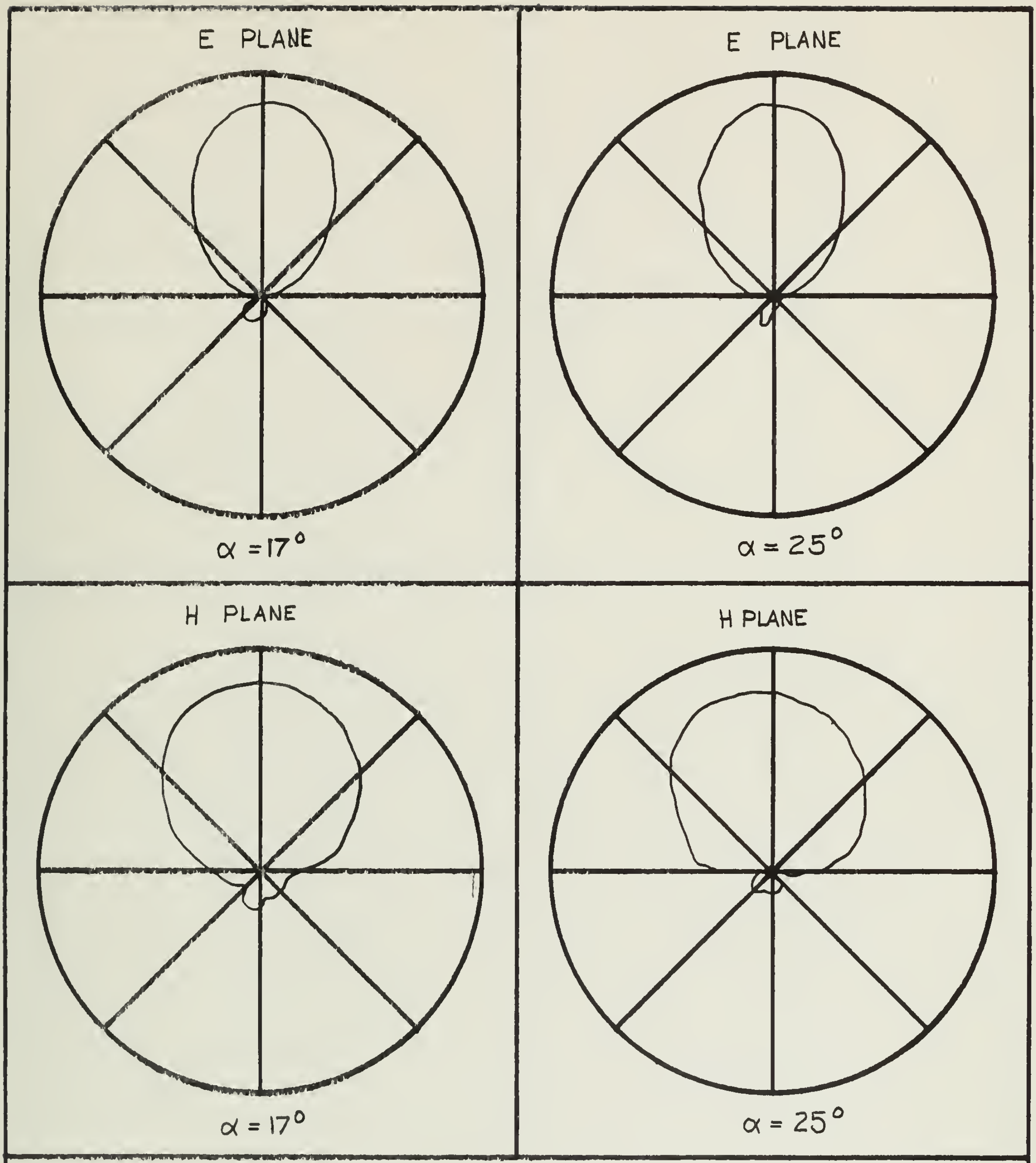


FIGURE 12 TYPICAL FIELD PATTERNS, $\tau = .95$

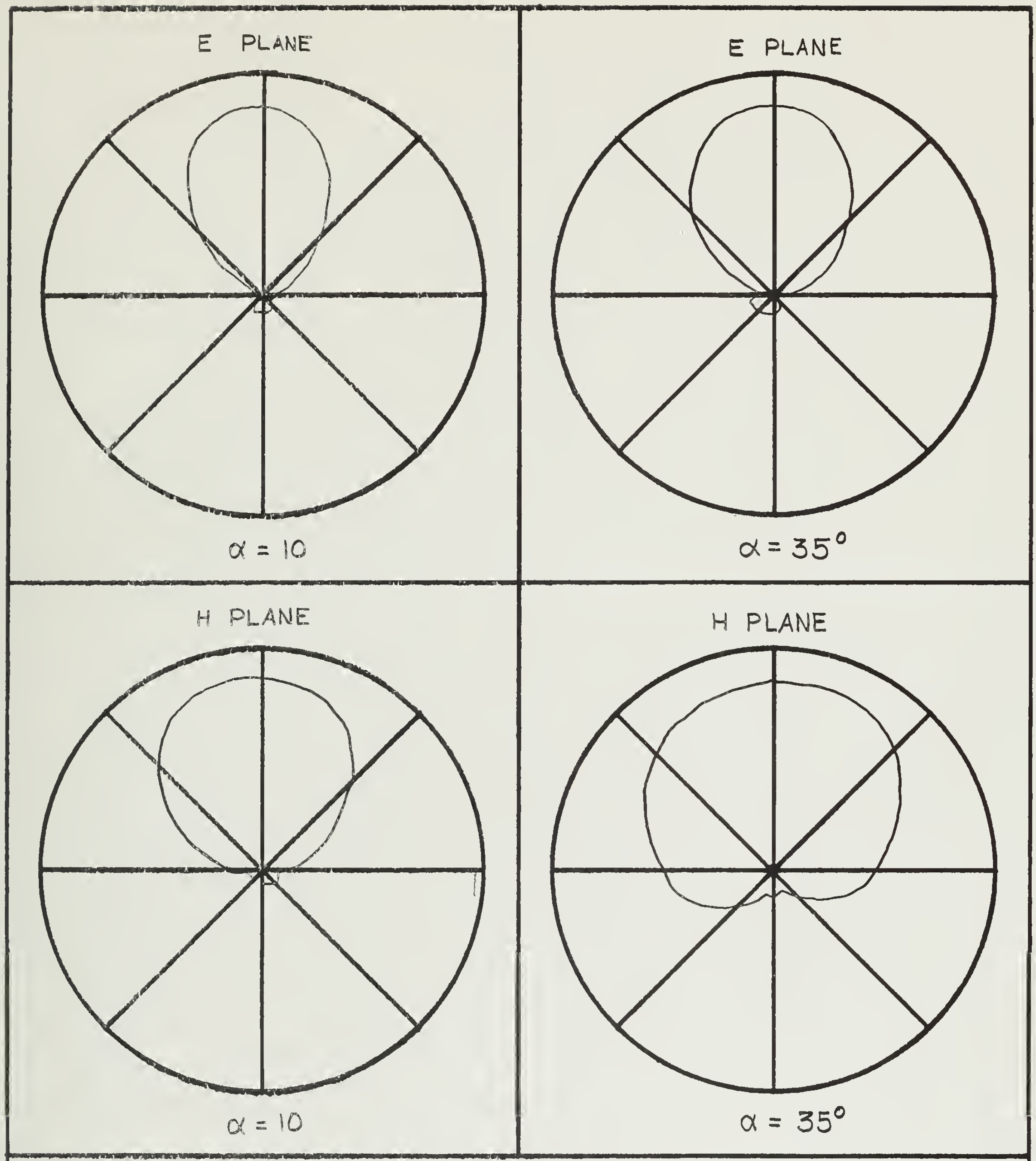


FIGURE 13 TYPICAL FIELD PATTERNS, $\tau = .89$

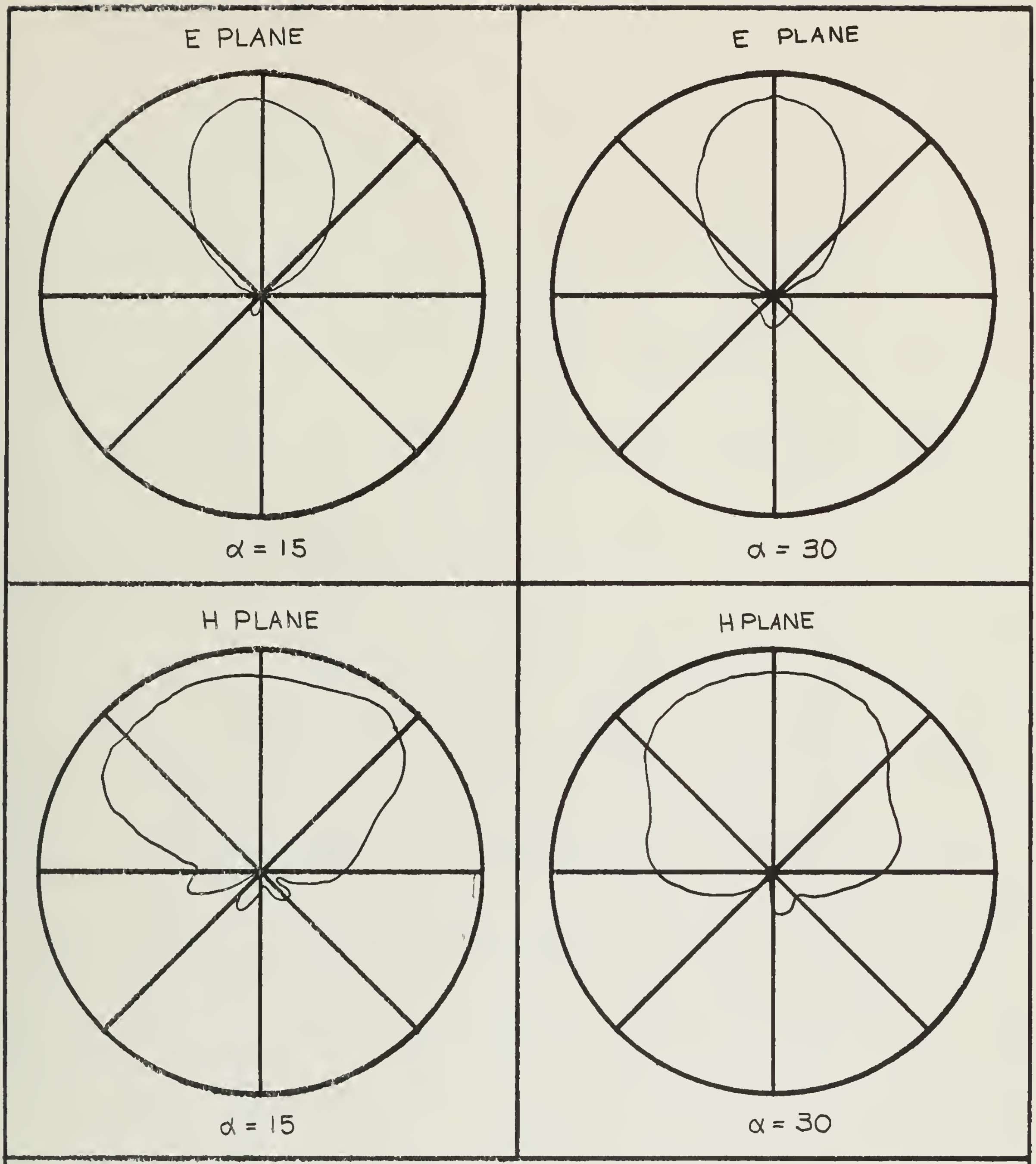


FIGURE 14 TYPICAL FIELD PATTERNS, $\tau = .81$

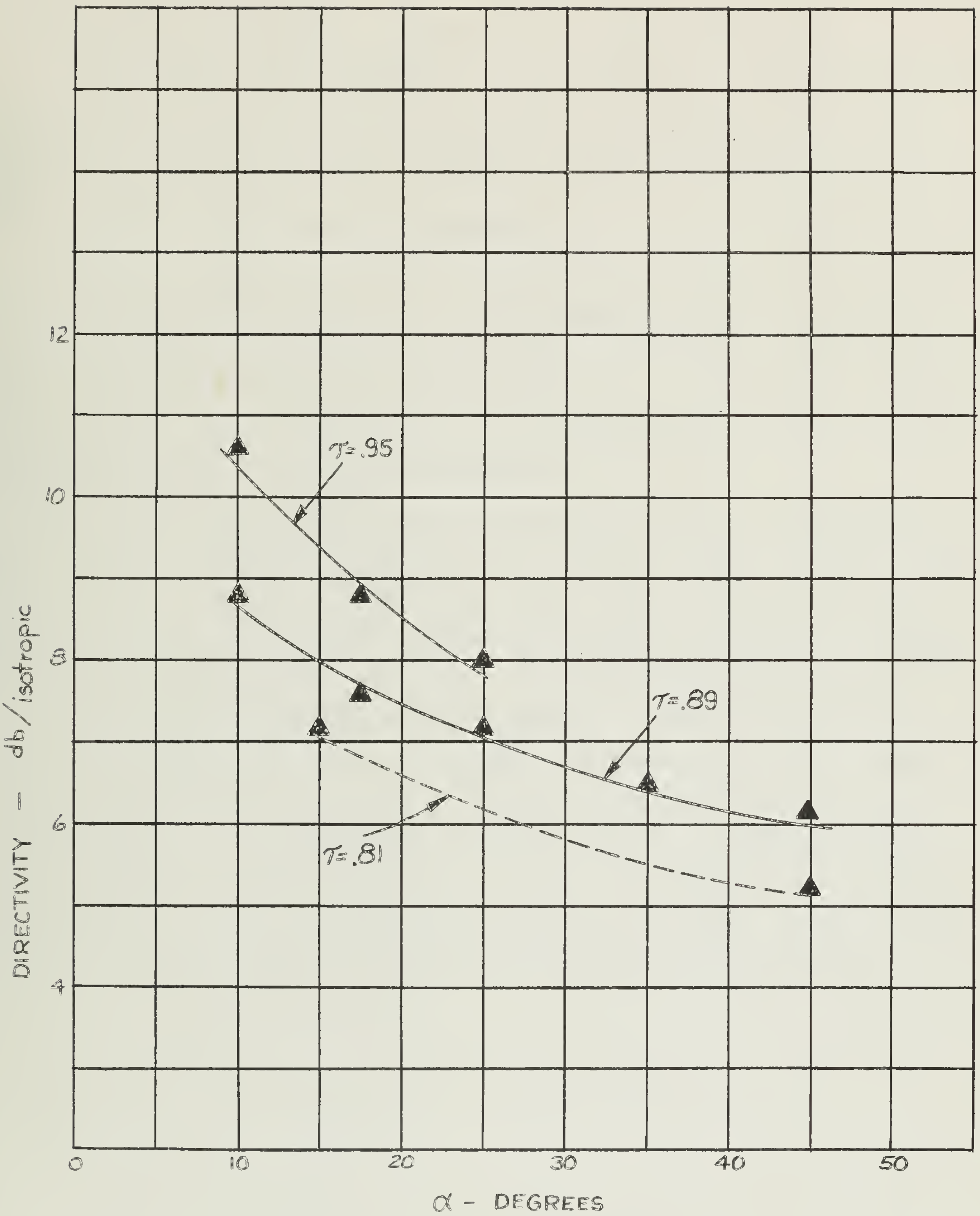


FIGURE 15 DIRECTIVITY VS. τ AND α

width The upper and lower frequency limits will be determined by lengths of the shortest and longest elements of the array respectively.

To determine this bandwidth for a particular array the antenna shown in Figure 16 was constructed. This antenna is defined by a τ of .95, α equal to 10 degrees, ℓ_1 equal to 2 1/2 inches, and the shortest element half the length of the longest. The array is 7 1/2 inches long and there are a total of fifteen dipoles included.

Radiation patterns for this array are shown in Figures 17, 18, and 19 over the band 1100 to 1800 mc/sec, and the directive gain, estimated on the basis of half power beamwidth, is shown in Figure 20. The minimum front-to-back ratio is 17 db and the directivity is better than 9 db over isotropic from 1130 to 1750 mc/sec. The variations in the directivity curve correspond closely to the periodicity τ.

A scaled up model of the array was assembled on the balanced line of the impedance measuring set up of Figure 7, and its input impedance was measured over a range corresponding to that of the radiation patterns above. The results of this measurement are shown in Figure 21 in terms of the standing wave ratio produced on a 72 ohm transmission line.

If the usable bandwidth of this antenna is taken to be the range from 1100 to 1800 mc/sec then the size of the antenna for any desired bandwidth is defined. That is, the longest dipole element should be approximately .47 wavelengths long at the lower limit and the shortest element should be about .38 wavelengths long at the higher wavelength. There will, of course, be some minimum number of elements necessary to provide a suitable front to back ratio at the low frequency limit.

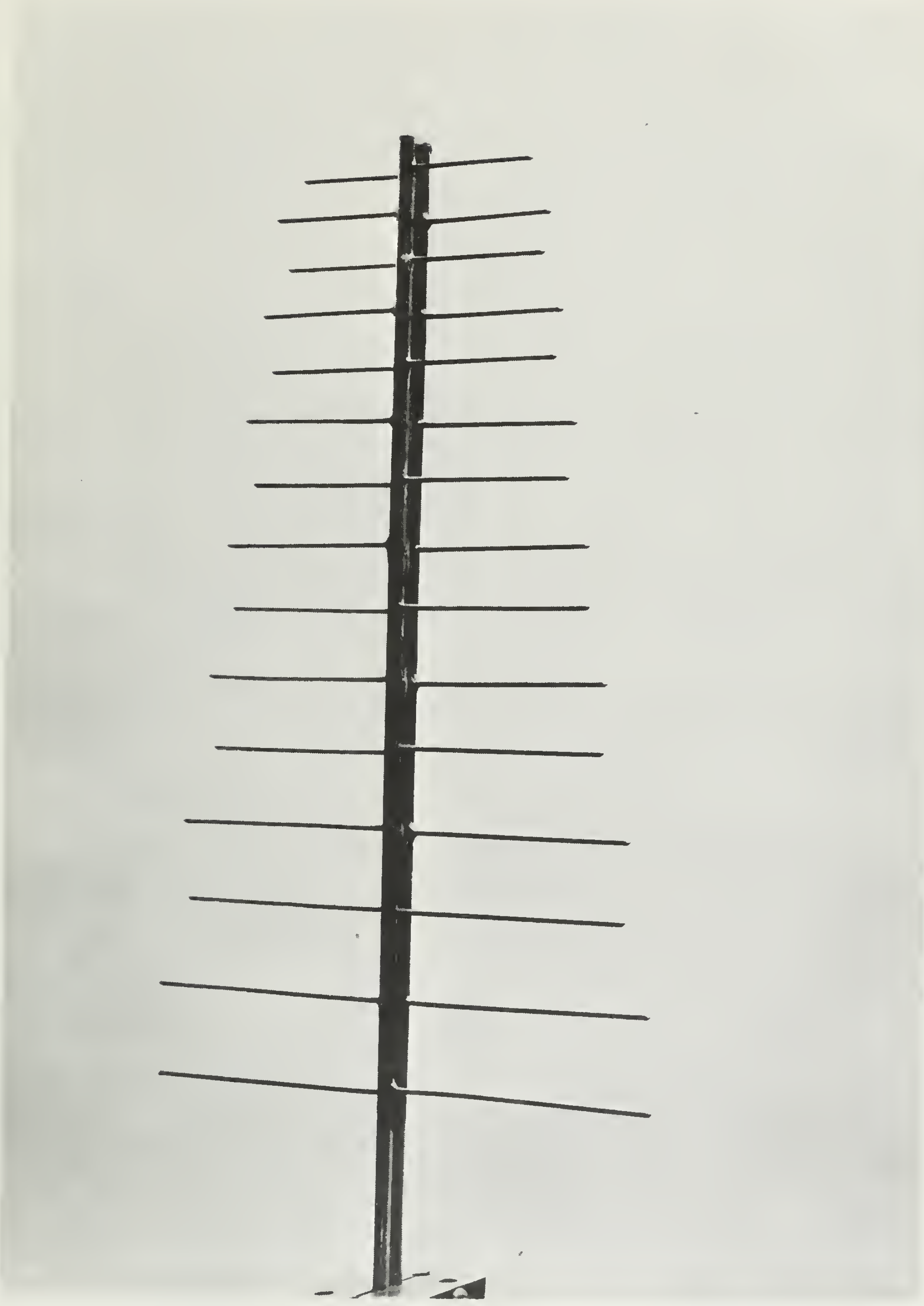


FIGURE 16 BANDWIDTH CONTROL MODEL

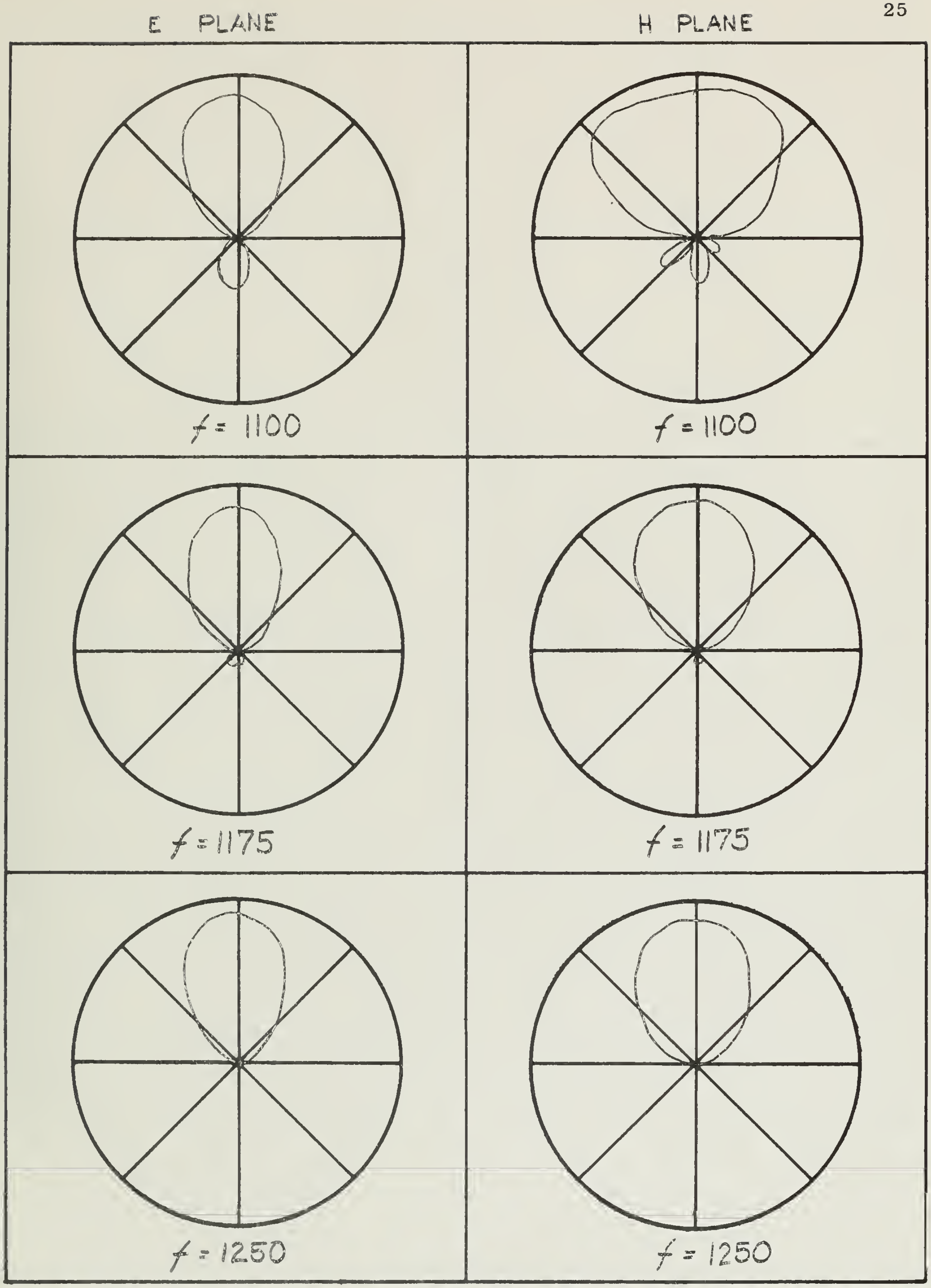


FIGURE 17 FIELD PATTERNS OF BANDWIDTH CONTROL MODEL

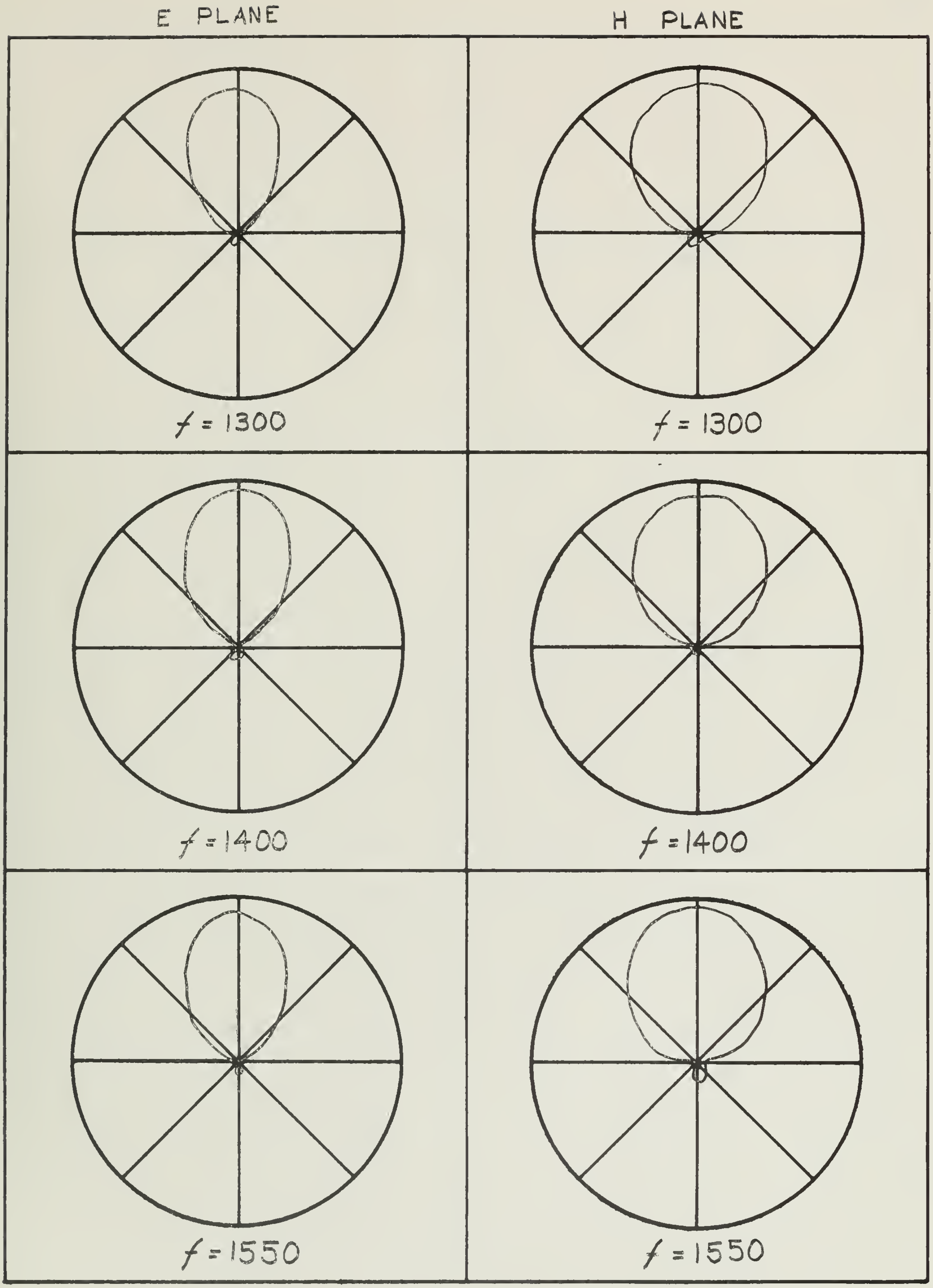


FIGURE 18 FIELD PATTERNS OF BANDWIDTH CONTROL MODEL

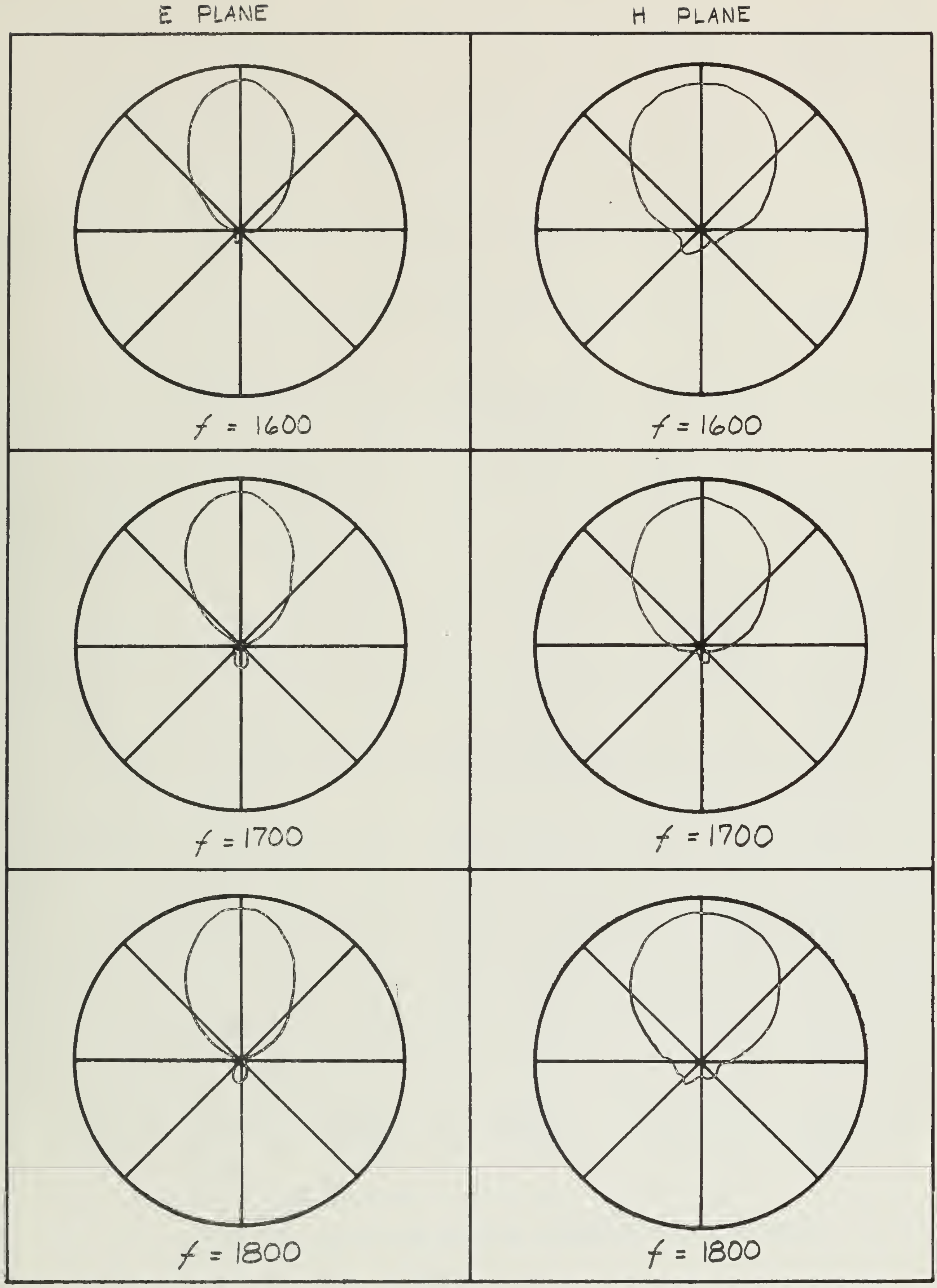


FIGURE 19 FIELD PATTERNS OF BANDWIDTH CONTROL MODEL

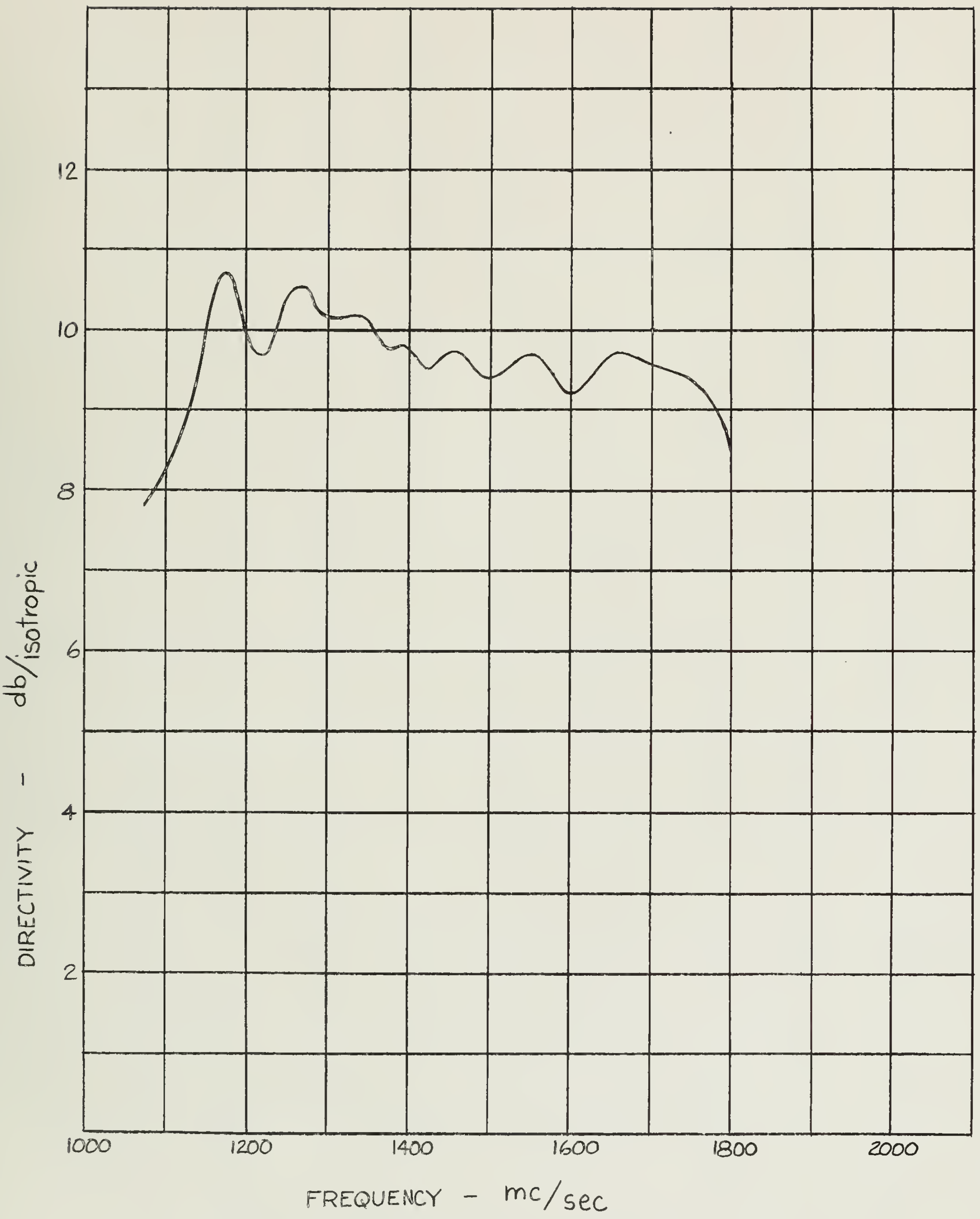


FIGURE 20 DIRECTIVE GAIN OF BANDWIDTH CONTROL MODEL

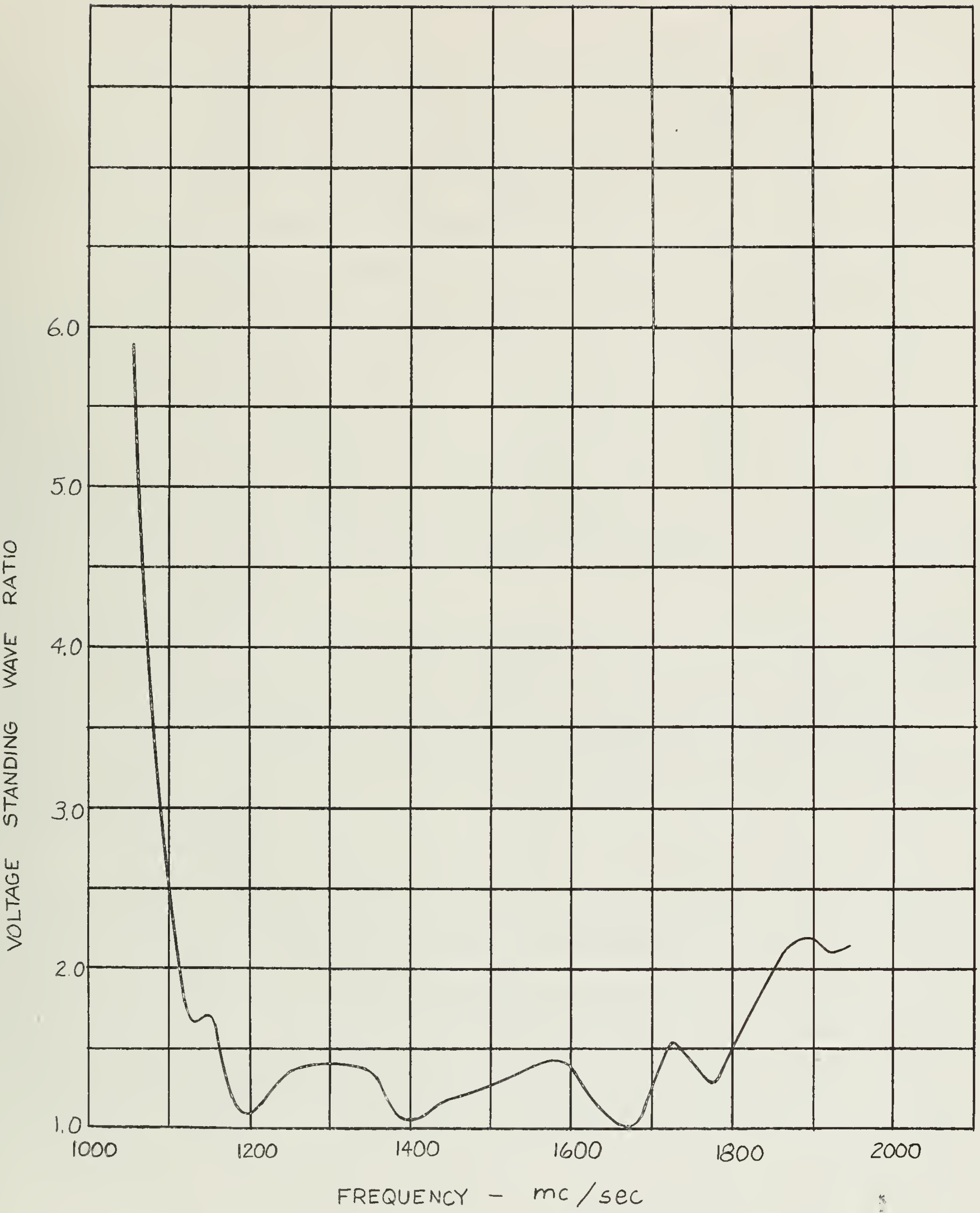


FIGURE 21 VSWR WITH RESPECT TO 72 OHMS

4. CONCLUSIONS

The arrays discussed in the foregoing paragraphs should prove useful in several applications. The model used to demonstrate bandwidth control shows that these antennas will make excellent rotatable beams, superior in many respects to the parasitic types currently in use. It is interesting to compare, for example, the antenna of Figure 16 to a 5 element Yagi.

A wide spaced, five element, Yagi adjusted to provide a midband front-to-back ratio of 25 db, will provide a 7% bandwidth with a front-to-back ratio of approximately 15 db at the edges. The midband directive gain of this antenna is slightly better than 10 db over isotropic, and its length is about .85 wavelengths. The log periodic beam of Figure 16 has fifteen elements but is only .73 wavelengths long at the low frequency end. The directivity stays above 9 db with the front-to-back ratio better than 17 db through a bandwidth of 43 percent, and the elements need no adjusting for this performance.

DuHamel and Berry have shown that the original log periodic elements can be arranged to provide directivities of up to 20 db, and those same principles may be applied to the dipole array where higher gains are required. Omnidirectional horizontal polarization and unidirectional circular polarization should be achievable by using the methods introduced by DuHamel and Ore.

In addition to the practical usefulness of the log periodic dipole arrays there is another equally interesting and important aspect of the design. The fact that these structures are made up of conventional linear elements seems to invite analysis in terms of familiar transmission line and array theory. To be sure, the problem is not a simple one even so, but its solution would be well worth while in the study of frequency independent antennas. This problem is presently being considered in this laboratory.

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